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AN EVALUATION OF THE RELATIVE ACCURACY AND PRECISION WITH WHICH TIME STUDY OBSERVERS USE TIMING DEVICES

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

The purpose of this study was to determine whether or not time study observers when using different types of timing devices exhibit significant differences in the accuracy and precision with which they read and record time intervals between the terminal points of work elements. In this study accuracy refers to the deviation of an estimate from the universe or true value. Precision refers to the standard deviation of a variable; the smaller the standard deviation, the higher the precision.

A review of the literature indicated that since the days of Frederick W. Taylor, many developments have taken place in the field of work measurement. The first standards were established on the basis of past performance records and foreman's estimates. As time passed, the stopwatch was used to record the actual time used by an operator. Ultimately, performance rating was developed to increase the reliability of stopwatch measurement. Also, there appears to have been considerable difference of opinion among time study men as to the best procedure for measuring standard time. Some have concentrated their efforts on the development of systems of predetermined motion-times. With these, standard times can be established by recording the basic

motion of an operation and summing the predetermined leveled tabulated times for these basic motions. Others have reasoned that minuteness of time measurement is not in itself a meaningful basis on which to judge the validity or even the reliability of the resulting data. They also have shown that basic motion times are not constant for all work situations. These time study men have developed several devices for improvement of the accuracy and precision of timing and leveling elements of work.

Due to the variations within work methods and the inaccuracies of measuring devices and observers in time study work, the standard is based on the average of a number of observations; the pertinent question is whether or not this average has acceptable accuracy and precision for the use to which the resultant data are to be put. A reduction in the variability of observations will allow a reduction in the number of observations.

In this study, the hypothesis was made that standards established by the use of the different timing devices would show statistically significant differences and that one of the devices would require fewer observations than the others to give equal results. The experiment was based on a Latin square design. A Latin square is an experimental design in which the effects of one factor are grouped according to levels of two other factors, the levels of the first factor being assigned at random, with the restriction that no one level of the first factor will appear more than once with any given level of either of the other two factors. Level is defined as a given value for any of the factors. Five timing devices were used in this study. These were the stopwatch, marsto-chron, auto-graphic timer, wire recorder, and electronic timer.

In order to eliminate variability in performance, a special device was used to simulate the timed operation. Observers with essentially equal time study training and experience and learning ability operated the five devices. The observer personal data were obtained from employer's records. Observations were made of light flashes generated by the special device. The arithmetic mean and the standard deviation were calculated for each element of the time study, and analysis of variance techniques were employed to evaluate the components of variance within these two statistics.

The mathematical model to describe this experiment is:

$$x_{ij(k)} = \mu + M_i + D_j + O_k + \epsilon_{ij(k)}$$

taken from the table below. It states that the value of any observation is equal to a constant plus variations due to the observers, the devices, the order of test, and the errors of the experiment.

Source of Variance	Abbreviation	Subscript	Symbol	Number of Levels
Observers	M	i	M_i	5
Devices	D	j	D_j	5
Order of Test	O	k	O_k	5

Based on the results of the statistical analysis and within experimental limitations, the conclusion reached was that the different timing devices do, in fact, produce different results. Indications are that the stopwatch produces the least accurate and least precise results and that the marsto-chron is somewhat more accurate than the stopwatch but less accurate and less precise than the other three devices. The differences between the electronic timer, the wire recorder, and the auto-graphic timer were not significant. Differences between observers were not significant; therefore, it can be stated that well qualified observers with equivalent experience when using the same device will give statistically equivalent results. The analysis indicates, however, that the stopwatch in the hands of well experienced observers produces a somewhat smaller standard deviation than was reported by Lazarus, Magar, and Leng. The stopwatch and the marsto-chron are inadequate for timing and rating elements shorter than 0.09 minute and 0.07 minute respectively, especially when these occur in sequence, while the auto-graphic timer, the wire recorder, and the electronic timer give acceptable accuracy and precision for elements as short as 0.03 minute duration and also have adequate provision for the observer to record his rating.

It is recommended that further investigations be made comparing other timers with the more accurate of the timers used in this experiment. Investigation also is recommended of the effect that the recording of leveling factors would have on the accuracy and precision of the three devices which showed non-significant difference. The possibility that the results of this experiment do not represent those which would occur under actual time study conditions should be investigated. An investigation should be made of the relative accuracy of time standards established by predetermined motion-time systems and those established by one of the more accurate devices used in this study. There is a need to establish some guide so that the required level of detail and accuracy in work measurement may be more closely related to the requirements of the purpose for which the measurement is made. This would indicate which of the several time study techniques should be used.

CHAPTER I

INTRODUCTION

Work measurement is necessary so that quantitative values will be available for assessing the probable results of proposed changes in work methods and so that decisions in terms of quantified reference points can be made for managerial control purposes. Standard time is one of the forms in which this requirement is stated. There is no universally specified level of detail or accuracy to which the measurement must be made. The degree of detail is determined by the variability of performance times and the requirements of the use to which the result is to be put.

Since the days of Frederick W. Taylor, many developments have taken place in the field of work measurement. Standards have been established on the basis of past performance records and foreman's estimates and by means of the stopwatch. In the early days of time study the stopwatch was used as a means of recording the actual time spent by an operator, and ultimately became the tool for establishing piece rates. As time passed it was recognized that actual time was not dependable as a basis for work measurement. Therefore, a number of systems for adjusting actual time to allowed time were devised.

Some of these methods were b sed on the use of average, minimum, or modal time in various combinations. Ultimately, performance leveling was developed, and is still widely used throughout the world. The use of the leveling technique greatly improved the reliability of time tudy measurement; but it still depended to some extent on the element of human judgment.

As early as 1900, time study men saw the need for standardized time standards which could be used throughout industry. In order to attack the problems of work measurement more scientifically, many different techniques have been developed by time study men. These techniques have been developed following two different theories. Some of these men have expended their efforts toward the development of predetermined motion-time systems which give the leveled times for basic work motions. Others have concentrated on development of more accurate methods of timing and rating somewhat broader elements of work.

Developers of the predetermined motion-time systems recognized the effect of distance moved and body member used on the time to perform manual motions. In order to make the data from time studies and/or motion picture films of maximum value, very complete and detailed information was recorded for each work motion. Each operation was subdivided into several elemental motions in the expectation that the variables affecting time would be clearly distinguishable. Each motion was classified according to the distance moved, the body member used, the type and degree of manual control involved, and the weight or resistance encountered. The time values for each element of work were tabulated according to these variable factors, were analyzed, and were correlated to determine motion times. Use of the techniques of these systems make it possible to record the characteristics of a motion symbolically, and from this analysis to derive the standard time, using the motion time tables of the particular system being used.

While predetermined motion-time systems were being developed, time study men were also trying to improve the techniques of measurement and rating in time studies. Time study is a method of measuring the work content of human tasks. This method requires a measurement of the time consumed in performing work. It implies careful measurement of all work elements by means of some precise instrument developed for that purpose. It seems that advocates of this procedure believe that predetermined motion-times can never be used universally because motion times cannot be considered constant for all work situations. Since motion times were not adequate for establishing standard time, the alternative seemed to be to improve the accuracy and precision of methods for timing broader elements of work so that the resultant standards would be suitable for work measurement requirements. It was necessary also to improve the methods by which the time study observer could assign leveling factors to accompany the measured actual or elapsed times.

Throughout the history of time study, but particularly since about 1940, several time study devices, both electro-mechanical and electronic, have been developed *for the purpose of improving the accuracy and precision of* timing elements of work. Although these devices have not received widespread usage, it seems quite possible that use of one of these devices could lessen the disadvantages of conventional practices in timing.

There appears to be a need for evaluating these devices to determine whether one of them would, in fact, give a more accurate standard than the others. Due to variations within work methods and inaccuracies of timing and rating, the standard at any level of detail is based on the average of a number of observations; the pertinent question is whether this average has acceptable accuracy and precision. The degree of detail of the time measurement unit is not in itself a meaningful basis on which to judge the validity or even the reliability of the resulting data; rather, these depend upon the accuracy and precision of the measurement and the reliability of the rating.

Based on the available information regarding timing devices, it was decided to investigate the hypothesis that time study observers when using different types of timing devices exhibit significant differences in the accuracy and precision with which they read and record time intervals between the terminal points of work elements. Webster's Unabridged Dictionary gives these meanings for accurate and precise:

accurate - in exact or careful conformity to truth, or to some standard

precise - minutely exact; not varying in the slightest degree from truth, accuracy, standard

In this study accuracy refers to the deviation of an estimate from the universe or true value. Precision refers to the standard deviation of a variable; the smaller the standard deviation, the higher the precision.

In this study five timing devices, including the stopwatch, were used to record elements of a simulated operation for which the true element time values were known. Statistical analysis of variance techniques were used to classify the variances of individual observations into meaningful components. These components were tested for significance by means of the Fisher variance ratio test. Based on these analyses, a determination as to which device would give the most acceptable time study results was made.

Certain limitations were inherent in the design of this experiment. No dynamic factors likely to be encountered in actual time study practice were present. Also, the observers were not required to record a rating; and only fully qualified observers were used in this study.

CHAPTER II

SURVEY OF LITERATURE

Frederick W. Taylor was the first to use time study when in 1881 he received permission from the president of the Midvale Steel Works "to find out how quickly the various kinds of work that went into the shop ought to be done (1)." Taylor's objectives were to determine labor standards for a "fair day's work" and to help the workmen in achieving those standards by showing them proper work methods. Essentially the same technique of stopwatch time study introduced and developed by Taylor is still used extensively by time study men today.

There are many limitations in using stopwatch time study techniques for work measurement purposes. These limitations have been the subject of numerous studies during the history of work measurement. As has been pointed out by Lehrer (2) and Presgrave (3), most stopwatches used in time study are calibrated in 0.01 minute divisions, with a probable error of 0.005 minute associated with each individual reading. Since in most time study work the watch is read with the hand in motion, the observer has to "glimpse" the reading to the nearest hundredth minute whether using snap-back or continuous timing. Several studies have been done concerning the relative accuracy and precision of these two most popular timing methods. In one investigation, Swerdlove and Llewellyn (4) had observers time an operation of five elements ranging in duration from 0.04 to 0.15 minute by viewing motion pictures. From their statistical analysis, within certain limitations dictated by the circumstances under which the data were gathered, the following conclusions were drawn:

> "1. There is a definite bias or tendency to read elements too short when using the snap-back method; when the proper correction is applied for this bias, however, the two methods produced about the same results.
>
> "2. Elements shorter than .05 minutes can be timed and, in some circumstances at least, elements as short as .04 minutes can be timed accurately with either method."

In a later study, Lazarus (5), by using both visual and audible stimuli for elements of from 0.04 to 0.39 minute, found that the standard deviation was equal to 0.0081 minute for both methods of timing but that the continuous method showed less deviation from the true mean. Abruzzi (6) reported essentially the same results in a similar study. In his investigation, observers used both methods to time a skilled operator in a three element bolt and nut assembly operation which averaged 0.10 minute in duration. Statistical tests showed element and cycle times to be significantly smaller by the snap-back method. The difference between cycles was less pronounced than between elements. Standard deviations for elements and for cycles were found to be of the same order of magnitude for both methods. "Thus, the snap-back method is less accurate than the continuous method, where accuracy is measured in terms of the error of estimate. However, the two methods are equally precise, where precision is measured in terms of the degree of variation." About short elements, approximately 0.02 minute in duration, Abruzzi had this to say:

> The almost constant readings for the first element bring up a point of fundamental importance concerning measurement methods and their properties. These readings illustrate the fact that constancy appears to exist when the element observed is of the same order of magnitude as the measuring instrument. This implies that constancy is not a property of the element itself. Instead it shows that the measuring instrument is inadequate under these conditions and should be replaced by one which is more sensitive.

A number of techniques have been developed to aid the observer with the problem of gathering accurate data. Barnes (7) and Mundel (8) suggest that the observer hold the time study board so that the watch is in the line of vision between the observer and the operator. This enables the time study observer to more easily concentrate on the three items demanding his attention - the watch, the operator, and the observation sheet. Along somewhat the same line of thought, Lowery, Maynard, and Stegemerten (9) reasoned that "eye-strain" and "tendency toward uncertainty" would be greatly relieved on the part of the time study observer if his eyes were "kept directly on the watch" rather than shifting from watch to operator. This suggestion means that the observer should place himself such that he can focus his vision on the stop watch and still see clearly the movements of the operator in the background. Two other methods of timing, accumulative and a three watch method called "Quick-Click," have been used to a limited extent. These would seem to give greater ease and accuracy of reading since the hand of the watch is not in motion at the time the watch is read. Barnes (10) describes accumulative timing as follows:

> These [two] watches are mounted close together on the observation board and are connected by a lever mechanism in such a way that, when the first watch is started, the second is automatically stopped. When the second watch is started the first is stopped. The watch may be snapped back to zero immediately after it is read, thus making subtractions unnecessary.

Cyrol (11) discusses a method of using three watches mounted on a special time study board and operated by one lever. Each click of the lever starts one watch, stops one, and snaps one back to zero. This allows the observer to read the locked-in-place time for each preceding element while timing the successive one.

Closely related to the limitations of stop watch reading is the question of how many readings to take. The number of watch readings required to obtain an acceptable mean element time always has been a controversial part of time study procedure. Some time study observers "select" a good elemental value by inspection from the individual recordings. Another group of observers rely on some arbitrary number of observations to give what is believed to be an accurate mean. There is a relatively new approach that is gaining support rapidly, but it has the disadvantage of being merely a check on the adequacy of the number of observations from a statistical viewpoint. Here, "the observations are analyzed by statistical methods to determine reliability, and if the values are not satisfactory then additional observations must be obtained" (12). The variability of the observed times can be used to estimate the number of additional observations required for a given reliability.

Statistical analyses used to determine observation adequacy of the time study sample have indicated that the variability of individual observations contains two elements:

1. Timed variation - due to many chance happenings such as operator actions or variations in methods, materials, equipment performance, workplace layout, etc.

2. Timing variation - due to the characteristics of the timing device and the observer using it.

In a study to analyze some of the causes of timed variation, Forrester (13) found no evidence of a relationship existing between the timed variance and the length of the element, but the correlation between the timed variance and complexity of elements was, statistically, highly significant. The results of an investigation by Magar (14) concerning timing variation indicate that:

> The primary cause of errors in watch reading is variability within the observer, ...[and] ... it appears that the magnitude of watch reading error cannot be reduced by better selection of time-study trainees, but should be effected by training programs directed at all time-study men in a company regardless of experience ....
>
> It also appears that the rule of thumb limiting time-study elements to at least .05 minutes is valid .... Finally, the standard deviations observed in this experiment for watch reading errors ranged from .005 to .01 minutes and averaged between .007 and .008 minutes. This agrees closely with the results of Mr. Lazarus for visual break point elements.

Some time study authorities believe that the more minute the measurement, the more useful is the result. An outgrowth of this belief has been the several predetermined motion-time systems such as "Work Factor" (15), "Methods-Time-Measurement" (16), and "Basic Motion Timestudy"(17). Time studies and/or motion picture films of many types of operations were studied and the operator activity was categorized into certain basic motions. These motions were classified according to the distance moved, the body member used, the type and degree of manual control involved, and the weight or resistance encountered. Leveled times for performance were assigned to these motions from analysis and correlation of the variable factors. To use the system a time study man merely has to analyze any manual operation into its basic motions, select and record, from tables, times for these motions. The sum of all the motion times gives the standard time for the operation.

These systems imply that elements and motions have constant times under any conditions. This probably is not true according to Nadler and Wilkes (18) who found that to change the mechanical procedure for one therblig (basic motion) produced statistically significant changes also in the times of the adjacent therbligs in the motion pattern. In a somewhat different type of experiment, Nadler and Denholm (19) arrived at almost the same results and conclusions. After a statistical analysis of different tests, Abruzzi says: "These findings, then, clinch the argument against the claim that elements (and motions) have constant times ...(20)." Using analysis of variance techniques to compare three motion-time systems, Davidson (21) concluded:

> Therefore, on the basis of the evidence analyzed in this investigation we cannot believe the claims of accuracy advanced in behalf of these systems. True, one of them <u>might</u> be accurate. But all are equally suspect, and <u>until</u> the advocates of some one of them can produce objective evidence of accuracy we prefer to regard all the claims with some skepticism.

M-T-M authors also contend that when two motions are performed simultaneously, the one requiring the more time is a "limiting motion." They use the analogy (22) of reading a letter which requires 5 minutes while riding to work which requires 15 minutes to support their reasoning that only the time value for the motion requiring the greater amount of time should be used. Davidson (23) points out that this analogy does not actually correspond with the case of combining motions since the operator would not be actively involved in both operations. He says there is adequate experimental evidence to reject this reasoning, but "if no other considerations at all were involved, the uniqueness of the M-T-M elements would appear to be denied by the assumption of a 'limiting motion'."

After a study of the literature in the field of time study, one is led to the conclusion that neither the techniques of stopwatch time study nor those of predetermined motion-time systems will adequately satisfy the two fundamental reasons for measurement: (1) so that quantitative values will be available for assessing the probable results of proposed changes in work methods and (2) so that those who will use the measurement for control purposes can make decisions in terms of quantified reference points. It is therefore apparent that a requirement exists for a time study technique which will establish time study data to the required degree of detail with a satisfactory degree of accuracy.

In view of this requirement, several time study devices have been developed for the purpose of improving the accuracy and precision of timing elements of work. As early as 1907, Frank Gilbreth developed a spring driven timing machine called a microchronometer. In 1919, Merrick emphasized the need for a more accurate timing device in his paper, "Time Studies for Rate Setting" (24). Soon thereafter, Williams developed a time study machine (25). This was a spring driven device which had pens tracing lines on a strip of paper which moved at a uniform rate.

The next noteworthy machine, developed by Marston (26) in 1938, was called "Marstro-chron." This device had six keys which actuated pens normally bearing against a paper strip which moved ten inches per minute. The time duration between the successive elemental end-points on the paper was measured by means of a special transparent scale graduated in 0.01 inch increments. Elemental times were estimated to 0.001 minute through the use of this scale. The original marsto-chron was later refined by reducing the number of keys from six to two and replacing the pens, which originally scribed during the time the respective elements were not being performed, with inked markers which mark the paper only when the keys are depressed. A limited number of different elements may be identified by adopting a code pattern of the two keys.

A device called a "Wink Counter" was originated by Porter (27) in 1939. This device has three revolving discs each having numbers about its circumference from which the time can be read accurately to 0.005 minute for time studies. For motion study, a helix may be used on the device and an accuracy to the nearest "wink" or 0.0005 minute is attainable.

Thuesen has developed three time recording devices for use in motion and time study. The first of these is a complex device (28) which records twelve elements to the nearest 0.0001 minute. This machine was built for research in motion study. Thuesen's second timing device (29) is intended more for time study work. It is approximately three inches thick, shaped similar to a time study board, and has approximately the same surface area as a time study board. Elements of time are obtained by driving two print wheels with a synchronous motor. These wheels are graduated from 00 to 99 around the circumference and are geared so that they record to the nearest 0.001 minute. The time recording is accomplished by operating a lever which depresses a hammer, surrounded by an inked ribbon, against a strip of paper which is directly over the print wheel. The strip of paper advances one position after each recording. Identifying notes and symbols may be written beside each recording. Thuesen's latest timing device (30), is an improvement over the one just described. It will directly record elapsed times of work elements of 0.001 to 9.999 minutes' duration to the nearest 0.001 minute. Five lettered keys are provided for identifying elements for which the recorded times apply.

A somewhat different approach to the time study recording problem was made by Jones (31) in 1949. In this time study method, a wire recorder is set up near the operation to be time studied. The time study man sharply taps the microphone at the end of each element in the study. He records other information about the operation by speaking into the microphone. After the time study is completed, the recorded information is "played back." Using a revolution counter geared to the recording wire take-up drum, the time intervals between successive taps (elemental times) are read to the nearest 0.001 minute and are posted to a time study sheet. Other recorded information also is posted to the time study sheet.

Jones developed another type of timing device in 1952 (32, 33). This was later improved and called the "Auto-Graphic Time Study Machine" (34). This device has a cylinder 12 3/8 inches long by 4 inches in diameter driven by a synchronous motor at either 4 or 40 revolutions per minute. Around this cylinder are six mutual, time chart-bearing slip-fit shells. A recording and indexing mechanism and shell start and stop relays complete the array of components. For the recording of data, a properly calibrated graphic chart representing a time study element is placed around each of the six shells. These charts may be scaled for both actual and leveled times. At the end of each element of a time study, the observer taps a switch knob corresponding to the element being timed. This causes two relays to operate simultaneously. One posts a "reading" to the proper time chart and the other causes the succeeding time chart to start revolving. Proper indexing of the posting mechanism to compensate for above or below normal pace will allow leveled times to be posted. At the completion of a time study, the charts are removed from the shells and element times are read directly from the charts.

The field of electronics has been applied to work measurement in recent years. Rowe (35) describes an *experimental electronic time measuring* machine built by Clary Multiplier Corporation. This is a combination counting and printing unit. Accuracy is obtained by use of a quartz crystal which controls the pulse input to an electronic decade counter. Electrical pulses can be measured with this device to within one pulse in one million, or one millionth of a second. The counter feeds the accumulated pulses into a read-out machine which prints the time to the nearest 0.001 minute. Each element of each cycle can be identified by pressing keys which print an index number beside the respective time value. A leveling factor also may be printed beside the element time to which the rating applies.

"Unfortunately, factual data on the comparative accuracy and precision of all the time-measurement instruments discussed earlier in this chapter is not available." This statement is made by Buffa in Section 3, Chapter 2, "Methods of Measuring Time," of the Industrial Engineering Handbook (36) after having described some of the devices which have been discussed here. He further states: "A few comparative studies have been made on the stop watch, the marstochron, and the wink counter in combination with a camera."

One of these studies was conducted by Leng (37) in 1941. His research revealed standard deviations of 0.00165 minute for the marsto-chron, 0.00426 minute for the wink counter, and 0.00947 minute for the stopwatch (continuous timing method). He concluded that two to five times as many observations are necessary with the stop watch as with the wink counter, and from ten to thirty times as many with the stop watch as with the marsto-chron.

The results of a study by Abruzzi led him to somewhat different conclusions (38):

1. "The accuracy of a measurement method depends on how it is used and, in the case of the stop watch, by whom."
2. The marsto-chron "yields essentially the same order of accuracy with an inexperienced observer as the stop watch does with an experienced observer."
3. "...the stop watch yields different degrees of accuracy with different observers."
4. "...all three measurement methods considered improved in accuracy as the size of the subdivisions increased."

5. "...all three methods and both stop watch observers had about the same degree of precision, that is, the range of variability was about the same."

Summary.--The accuracy of the different time-measurement devices depends upon the limitations of the device itself in terms of the smallest unit of time that can be read from the scale of the timer and upon the extent to which human errors enter into its use.

In the use of the usual time study stopwatch, the smallest unit on the dial is 0.01 minute. For time study purposes, the observer must divide his attention between several activities -- observing, rating, reading the stopwatch, recording the watch readings and the leveling factor, and other activities. Errors appear not to be great when fairly long elements are being timed, but for short elements, the errors seem to be excessive. Repetitive and continuous timing are the most common methods of using the stopwatch. Several studies have been made to determine the relative accuracy of the two methods. Indications are that they are equally precise, but continuous timing appears to be more accurate.

Certain timing devices involve, in general, less complex observing and recording difficulties than does the stopwatch. Although the smallest unit is 0.001 minute on most of the devices, the observer can direct hi attention to the operation and press buttons, or otherwise activate the device, at the appropriate instant without removing his attention from the operation. The difficulty of recording other data pertinent to the time study varies with the type of device being used.

There appears to be a need for evaluating these devices to determine whether one of them would, in fact, give a more accurate standard than the others.

CHAPTER III

EXPERIMENTAL DESIGN

Assumptions and Parameters.--The limitations and deficiencies brought out in the survey of work measurement literature indicate that the requirements of precision and accuracy have not yet been achieved by either stopwatch techniques or by use of the predetermined motion-time systems. Further indications are that one or more of the mechanical or electronic timing devices may be capable of achieving these requirements, both from the standpoint of accuracy and precision of time measurement and from the standpoint of recording leveling factors.

Based on these indications and using estimates of the statistical parameters of mean and variance, it was considered desirable to test the available devices for relative accuracy and precision. If the relative accuracy and precision of the different devices could be determined from statistical analysis, it could be stated with assurance which of the devices would require the minimum number of observations to produce an acceptable standard and which should be used for a given level of time study detail.

<u>Procedure and Equipment</u>.--In order to test the hypothesis that there are significant differences in the results obtained by trained time study observers when using different timing devices, it was necessary to devise a procedure which would remove the timed variance from the experiment. This would leave only the timing variance to be subjected to statistical analysis.

Such a procedure was made possible by use of a specially designed piece of equipment shown in Figure 1 to simulate a six element operation. This device consists of a three RPM synchronous motor mounted on a base plate and with a plastic disc (3 inch diameter x 1/4 inch) mounted on the shaft. Near the circumference of the disc (on a 2 1/2 inch diameter circle), six copper inserts are placed through the disc at random intervals.

Contact points are mounted on the base plate in such a manner that they contact each side of the disc at the circle inscribed by the rotation of .e inserts. Electrical circuits are incorporated such that as the disc turns and the inserts pass between the contact points, a circuit is closed and a light is caused to flash. Six red flashes represent the six element end points. A white light flashes simultaneously with the red one at the end of each cycle. The speed of the disc is constant; therefore, the arc between any two inserts determines the time interval between flashes of light.

Figure 1. Special Device to Generate Element End Points.

In order to determine the duration of the six time intervals (with sufficient accuracy) this instrument was checked by a crystal controlled electronic decade counter which could be accurately read to one millionth of a second. This electronic timer is located at Robins Air Force Base and is used to check the precession of gyros used in aircraft Fire Control and Bombing Systems. The following data were obtained by checking ten cycles of the special instrument on the Air Force electronic timer. The data were recorded in seconds. The means and standard deviations were computed in seconds and converted to minutes.

Element	$\overline{x}$	σ_x
1	0.046379	0.000122
2	0.082955	0.000112
3	0.023702	0.000072
4	0.060809	0.000066
5	0.069382	0.000018
6	0.050104	0.000087
Cycle	0.333331	0.000084

These standard deviation values are extremely small and for purposes of this study, the $\overline{x}$ values may be considered as $\overline{x}$'values, the true element times.

Five of the timing devices described in Chapter II were used in this study. These were the auto-graphic timer, wire recorder, marsto-chron, electronic timer, and decimal minute stopwatch as shown in Figures 2, 3, 4, 5, and 6.

Five time study men who are currently doing time study work at Robins Air Force Base were selected to assist with the experiment. The qualifications of these men, taken from their employer's personnel records and shown in Appendix Three, indicate that they had very nearly equal training experience in the field of time study.

The reasons for the experiment, together with complete instructions as shown in Appendix Three, were read to the time study observers in a group. This was done to reduce the probability of any misunderstanding or misconception by an individual observer as to proper procedures.

Each of the observers timed for practice fifteen cycles of the "operation" using each of the devices. This was done to acquaint the observers with the characteristics of the devices and with the elements of the "operation." In the formal run, the observers also timed fifteen cycles using each device. Snap-back timing was used since the observers were using this method in their work.

The order in which each observer used each device was determined by a Latin Square Experimental Design (39) as shown below. Observer A uses device I first, V second; observer B uses device II first, I second; etc. This tends to balance out any effect due to Order and also permits an estimate to be made of the magnitude of this effect.

DEVICE	OBSERVER				
	A	B	C	D	E
I	1	2	3	4	5
II	5	1	2	3	4
III	4	5	1	2	3
IV	3	4	5	1	2
V	2	3	4	5	1

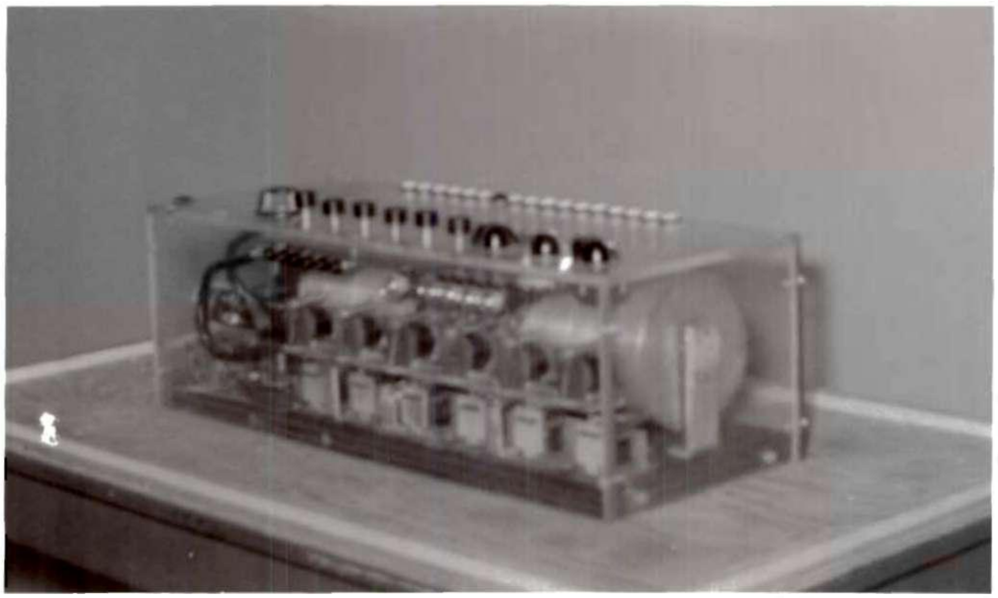


Figure 2. Auto-Graphic Timer

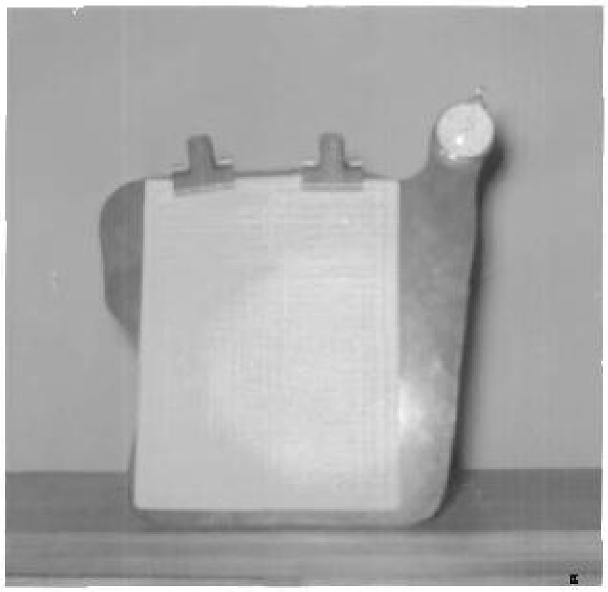


Figure 3. Stopwatch and Time Study Board

Figure 4. Wire Recorder

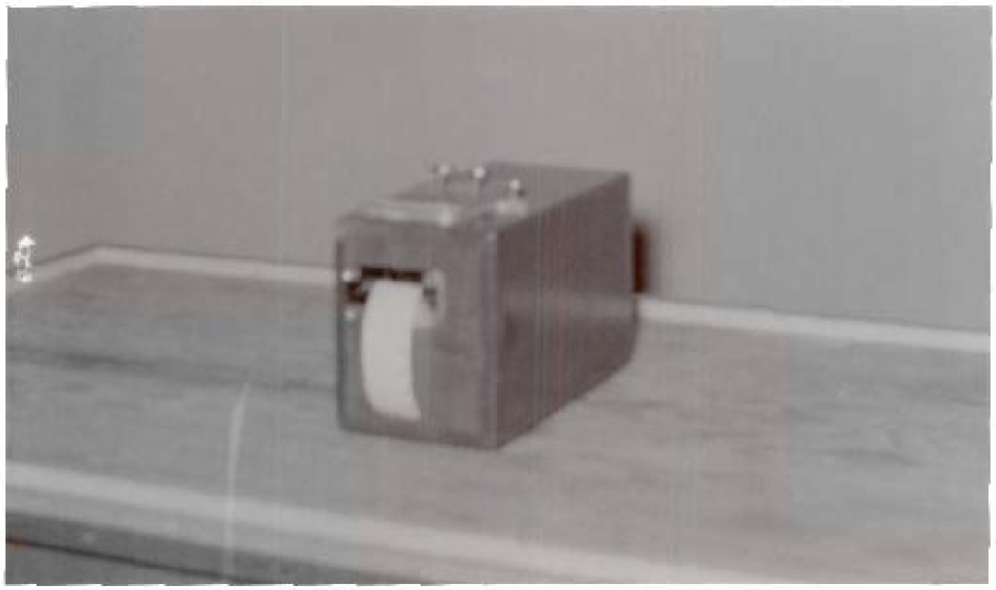


Figure 5. Marsto-Chron

Figure 6. Electronic Timer

CHAPTER IV

ANALYSIS OF EXPERIMENT

Introduction.--The main variables considered are observers, devices, and order of test. Use of the Latin square experimental design allows a substantial reduction in the error variance due to differences between order and between observers.

It was necessary to classify the variables as to fixed or random effect. Random variables are those "whose parameters involved are variances and their absolute and relative magnitudes are of primary importance" (40). Fixed variables are those "whose parameters involved are means and the issues of interest are concerned ... with the differences between pairs of them" (40). Devices and order of test were treated as fixed variables; and, therefore, were each fixed effects. The observers were not chosen at random from the population of time study observers, but rather were selected from one plant and were timing the same type of operations. Also, the records indicate their experience to be equal; therefore, they, too, were considered as a fixed variable with fixed effect. This classification of variables does not permit inferences about the whole population of devices or observers. Only differences between devices or between observers studied can be related.

The mathematical model to describe this experiment is:

$$X_{ij(k)} = \mu + M_i + D_j + O_k + \epsilon_{ij(k)}$$

taken from the table below. This states that the value of any observation is equal to a constant plus variations due to the observers, the devices, the order of test, and the errors of the experiment.

SOURCE OF VARIANCE	ABBREV-IATION	SUB-SCRIPT	SYMBOL	NUMBER OF LEVELS
Observers	M	i	M_i	5
Devices	D	j	D_j	5
Order	O	k	O_k	5

Measures of Objectives.--The objective of this study was to determine the relative accuracy and precision of different timing devices in the hands of trained time study observers. As stated in Chapter I, good time study results require that the observer (and device) have both accuracy and precision. An observer may get accuracy in the long run average, but with a small sample his mean value may be distorted by a wide range of readings or by readings with deviations predominately in one direction. Poor precision is indicated by a large standard deviation.

This problem was resolved by establishing that both the accuracy, measured by the mean, and the precision, measured by the standard deviation, would be analyzed separately. By analysis of variance techniques (41), these analyses were performed for each of the six elements of the data. Further analyses between devices were made based on single degree of freedom comparisons (42).

The real measure of accuracy is the error from the true mean rather than the observed elemental mean values. However, a shift in level by applying a constant to each number in a set of data in no way affects the relative variability of that data. Therefore, in this study the $\bar{x}$'s of the elements were used for analysis of relative accuracy.

The measure of precision used (the standard deviation, denoted by the Greek letter sigma) is the square root of the variance. The total variance equals the sum of the component variances if the factors producing variance are acting independently. In normal time study work the total variance of element means would be given by the expression:

$$\sigma^2_{\text{Total}} = \sigma^2_{\text{Timing}} + \sigma^2_{\text{Timed}}$$

The σ^2_{Timed} is not significant for this simulated operation, and the expression may be written as:

$$\sigma^2_{\text{Total}} = \sigma^2_{\text{Timing}} = \sigma^2_{\text{Device}} + \sigma^2_{\text{Observer}}$$

where $^2_{\text{Timing}}$ is reduced to its components. The element variances attributable to the total may be computed from the experimental data through use of the expression (43):

$$\sigma_{\text{Total}} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}$$

where: n = number of observations

x_i = value of individual observations

$\bar{x}$ = arithmetic mean of x_i's

Data Reduction.--Raw data which were posted by the observers on the time study observation sheets, marsto-chron tapes, wire recorder wire, electronic timer tapes, and autographic timer graphs were interpreted by methods described in Chapter II for the particular device and tabulated into usable form for statistical analysis. The original data tables were coded to ease the burden of calculation. From the tabulated data the statistics $\bar{x}$ and σ_x were computed by element for each observer - device combination. Appendix One contains samples of the original data, the tabulated data, and the element means and standard deviations.

One of the basic assumptions underlying the analysis of variance technique is that the experimental error in the individual cell observations are normally distributed. Normality is essential in order to make valid use of the Fisher variance ratio test (40). If they are not so distributed, a transformation of the data can be made which will develop the condition of normality.

This condition of normality is inherent in the data which was analyzed for accuracy. These data are $\bar{x}$ values and means are normally distributed even though the x_i's making up the $\bar{x}$'s may not be, for samples as large as those used in this experiment. An analysis of variance two-way observer-device table for element one is shown in Table I.

Inspection of the σ's of observations as seen in Table 15 indicates the possibility of an interaction between observers and the stopwatch; when there is only one observation for each factor combination, the variance of experimental error cannot be separated from that of any interaction that may exist. Also, due to the wide range and the preponderance of zero stopwatch σ's, it is obvious that the variability of the stopwatch is greater than that of the other devices. Therefore, the stopwatch σ's were not used in the analysis of variance for device σ's. Since variances are not normally distributed, the precision data in this study were logarithmicly transformed as recommended by Bartlett (44) and shown in Table 2.

Results.--This section presents the results of significance tests of the analysis of variance. The observer and order of test effects showed non-significance for both $\overline{x}$'s and σ's for all six elements in the basic analysis of variance mean square tables given in Appendix Two. These tables do, however, indicate that the device effect for $\overline{x}$'s is highly significant for all elements, while the device effect for σ's showed significance in only elements one, two, and four.

Comparison of devices was necessary to determine the relative accuracy and precision of the devices. Choice of the division of devices for single degree of freedom comparison was based on an engineering evaluation of the probable capabilities of the different devices. The single degree of freedom comparisons of device $\overline{x}$'s are shown in Tables 3 and 4. As expected, the difference between the stopwatch and all other devices is highly significant for all six elements. Significance also is indicated between the marsto-chron and the auto-graphic timer for element one and is very close to the 5% level for element six. The single degree of freedom comparisons of device σ's are shown in Tables 5 and 6. Differences between the marsto-chron and the auto-graphic timer are significant for elements one, and four, of questionable significance for element two, and

Table 1

Analysis of Variance
Two-Way Table
(Element 1 Mean)
With Sums of Square Calculations

Transformation = $\overline{x}(10^2)$

D_j \ M_i	A	B	C	D	E	$\sum_A^E$
I	4.75_a	4.65_b	4.70_c	4.70_d	4.69_e	23.49_I
II	4.00_e	4.33_a	4.00_b	4.00_c	4.06_d	20.39_{II}
III	4.63_d	4.61_e	4.61_a	4.66_b	4.69_c	23.20_{III}
IV	4.52_c	4.69_d	4.15_e	4.63_a	4.29_b	22.28_{IV}
V	4.64_b	4.69_c	4.64_d	4.78_e	4.70_a	23.45_V
$\sum_I^V$	22.54_A	22.97_B	22.10_C	22.70_D	22.43_E	112.81
$\sum_a^e$	23.02_a	22.24_b	22.60_c	22.72_d	22.23_e	$\sum_A^E \sum_I^V$

(1) $\dfrac{\sum(\sum_A^E)^2}{5} = 510.415$

(2) $\dfrac{\sum(\sum_I^V)^2}{5} = 509.132$

(3) $\dfrac{\sum(\sum_a^e)^2}{5} = 509.134$

(4) $\sum(x_{ij})^2 = 510.730$

(5) $\dfrac{(\sum_A^E \sum_I^V)^2}{25} = 509.044$

Device $\sum$ of Squares

= (1) − (5) = 1.371

Observer $\sum$ of Squares

= (2) − (5) = 0.088

Order $\sum$ of Squares

= (3) − (5) = 0.090

Total $\sum$ of Squares

= (4) − (5) = 1.686

Residual $\sum$ of Squares

= (4) − (5) − (1) − (2) − (3)

= 0.137

Table 2

Analysis of Variance
Two-Way Table
(Element 1 's)
With Sums of Square Calculations

Transformation = $\ln(\sigma \times 10^6)$

$D_j \backslash M_i$	A	B	C	D	E	$\sum_A^E$
I	6.96_a	6.89_b	7.14_c	7.13_d	6.78_e	34.90_I
III	7.64_d	7.42_e	6.66_a	7.43_b	7.20_c	36.35_{III}
IV	8.70_c	6.77_d	8.86_e	7.41_a	8.64_b	40.38_{IV}
V	7.12_b	6.96_c	6.89_d	7.55_e	7.18_a	35.70_V
$\sum_I^V$	30.42_A	28.04_B	29.55_C	29.52_D	29.80_E	147.33

(1) $\dfrac{\sum(\sum_A^E)^2}{5} = 1088.873$

(2) $\dfrac{\sum(\sum_I^V)^2}{5} = 1086.073$

(3) $\sum(x_{ij})^2 = 1043.268$

(4) $\dfrac{(\sum_A^E \sum_I^V)^2}{25} = 1085.306$

Device $\sum$ of Squares
= (1) - (4) = 3.567

Observer $\sum$ of Squares
= (2) - (4) = 0.767

Total $\sum$ of Squares
= (3) - (4) = 7.962

Residual $\sum$ of Squares
= (3) - (4) - (1) - (2)
= 3.628

Table 3

Significance of Device Means

Source	D.F.	Element 1		Element 2		Element 3		Element 4		Element 5		Element 6	
		$F_{1,20}$	Sig. Level	$F_{1,20}$	Sig. Level	$F_{1,20}$	Sig. Level	$F_{1,20}$	Sig. Level	$F_{1,20}$	Sig. Level	$F_{1,20}$	Sig. Level
Stop Watch vs. All Others	1	72.0	***	68.8	***	44.5	***	54.7	***	33.2	***	42.3	***
Auto-Graphic vs. Marsto-Chron	1	9.58	**									4.16	
Electronic vs. Others (Less Watch)	1	2.07		2.14						1.00		1.88	
Remainder Between Devices	1												
Residual	20												

$F_{1,20,0.05} = 4.35$ * Questionable Significance (between 5% & 1% level)

$F_{1,20,0.01} = 8.10$ ** Significant (above 1% level)

$F_{1,20,0.005} = 9.94$ *** Highly Significant (above 0.1% level)

$F_{1,20,0.001} = 14.80$ F Ratio not indicated if less than 1.0

Table 4

Sample Calculations for Device Means
Single Degree of Freedom Comparisons
(Element 1 $\bar{x}$'s)

Devices	Total Device Σ of Sqs.	Comparisons	d.f.
I. Auto-Graphic	1.361	II vs. I,III,IV,V	1
II. Stopwatch		IV vs. I	1
III. Wire Recorder		V vs. I,III,IV	1
IV. Marsto-Chron		Remainder	
V. Electronic		Between Devices	1

$$\text{General Formula for } \Sigma \text{ of Sqs.} = \frac{\sum_{i=1}^{5} (a_i T_i)^2}{n \sum_{1}^{5} a_i^2}$$

Devices	a_i	$T_i = \sum_A^E \bar{x}_1$	$a_i T_i$	a_i	$a_i T_i$	a_i	$a_i T_i$
I	-1	23.49	-23.49	+1	+23.49	-1	-23.49
II	+4	20.39	+81.56	0		0	
III	-1	23.20	-23.20	0		-1	-23.20
IV	-1	22.28	-22.28	-1	-22.28	-1	-22.28
V	-1	23.45	-23.45	0		+3	+70.35
$\Sigma a_i^2 = 20$		$\Sigma(a_i T_i) = 10.86$		$\Sigma a_i = 2$	$\Sigma(a_i T_i) = 1.21$	$\Sigma a_i = 12$	$\Sigma(a_i T_i) = 1.38$

Table 4 (Continued)

Sample Calculations for Device Means
Single Degree of Freedom Comparisons
(Element 1 $\bar{x}$'s)

(1) $\sum \text{sqs.} = \frac{(10.86)^2}{5(20)} = 1.1793$ for Stopwatch vs. all others

(2) $= \frac{(1.21)^2}{5(2)} = 0.1464$ for Auto-Graphic vs. Marsto-Chron

(3) $= \frac{(1.38)^2}{5(12)} = 0.0317$ for Electronic vs. Others (Less Watch)

(4) = Total - (1) - (2) - (3) = 0.0036 for Remainder

Source	d.f.	Mean Sq.	F	Sig. Level
2 vs. 1,3,4,5	1	1.1793	72.0	< 0.001
1 vs. 4	1	0.1464	9.58	< 0.01
5 vs. 1,3,4	1	0.0317	2.07	> 0.1
Remainder	1	0.0036	--	
Residual	20	0.0153		

have F ratios in the other elements high enough to be suspect when related to the three instances of significance.

The bias of the devices is summarized in Table 7 and the device standard deviations, or measures of precision, are shown in Table 8. These tables indicate that the marsto-chron is less accurate and less precise than all the devices except the stopwatch. Table 7 indicates that the stopwatch means were consistently lower than the true means. This was to be expected since previous studied by Llewellyn (4), Lazarus (5), and Abruzzi (6) have indicated that the snap-back method produces consistently low readings. This table also indicates that the marsto-chron bias was a large plus value for element six and a large minus value for element one. This indicates that the end point for element six was being posted late. A possible explanation for this is that at the end of each cycle the operator was required to press both keys on the marsto-chron rather than one as on all other elements. Apparently this disrupted the observer's rhythm and/or concentration enough to make the mean data significant for these elements and also to produce a high degree of variability in the data as shown in Table 8 for elements one and six.

Further analysis of Tables 7 and 8 shows that the variability in element four is slightly but consistently high for all devices while the bias for element four is a

Table 5

Significance of Device
Standard Deviation

Source	D.F.	Element 1		Element 2		Element 3		Element 4		Element 5		Element 6	
		F	Sig. Level	F	Sig. Level	F	Sig. Level	F	Sig. Level	F	Sig. Level	F	Sig. Level
V vs I,III,IV	1	1.24						2.13					
IV vs I	1	10.92	**	5.22	*	4.20		8.64	**	1.71		2.76	
III vs I,IV	1			1.37				1.04				2.62	
Residual	16												

Devices
I - Auto-Graphic Timer
III - Wire Recorder
IV - Marsto-Chron
V - Electronic Timer

* Questionable Significance (between 5% and 1% level)
** Significant (above 1%)
F Ratio not indicated if less than 1.0

$F_{0.05}(1,16) = 4.49$

$F_{0.01}(1,16) = 8.53$

Table 6

Sample Calculations for Device Standard Deviations
Single Degree of Freedom Comparisons
(Element 1 σ's)

Total Device Σ of sqs. = 3.567

Device	a_i	$T_i = \sum_A^E \sigma_x$	a_iT_i	a_i	a_iT_i	a_i	a_iT_i
I	+1	34.90	+34.90	+1	+34.90	-1	-34.90
III	+1	36.35	+36.35			+2	+72.70
IV	+1	40.38	+40.38	-1	-40.38	-1	-40.38
V	-3	35.70	-107.10				
$\sum a_i^2 = 12$		$\Sigma(a_iT_i) = 4.53$		$\Sigma a_i = 2$	$\Sigma(a_iT_i) = 5.48$	$\Sigma a_i = 6$	$\Sigma(a_iT_i) = 2.58$

(1) Σ sqs. $= \frac{(4.53)^2}{5(12)} = 0.342$ for V vs. I, III, IV

(2) $= \frac{(5.48)^2}{5(2)} = 3.003$ for IV vs. I

(3) $= \frac{(2.58)^2}{5(6)} = \underline{0.222}$ for III vs. I, IV

Total = 3.567

Source	d.f.	Mean Sq.	F	Sig. Level
V vs. I,III,IV	1	0.342	1.24	>0.1
IV vs. I	1	3.003	10.92	<0.01
III vs. I, IV	1	0.222	--	
Residual	16	0.275		

Table 7

Differences in Measured Time and True Time
(Hundredths of a Minute)

Device	$\overline{x}_d - \overline{x}'$ for Elements					
	1	2	3	4	5	6
Auto-graphic	+0.060	-0.137	+0.012	-0.185	-0.146	-0.008
Stop Watch	-0.560	-0.683	-0.318	-0.829	-0.714	-0.292
Wire Recorder	+0.002	-0.159	+0.008	-0.205	-0.190	+0.038
Marsto-Chron	-0.182	-0.141	+0.054	-0.137	-0.134	+0.138
Electronic	+0.052	-0.043	+0.004	-0.101	-0.052	+0.136
True $\overline{x}$	4.638	8.296	2.370	6.081	6.938	5.010

$\overline{x}_d = \frac{\sum_A^E}{5}$, where $\sum_A^E$ are given in Tables 2 and 22-26.

Table 8

Standard Deviations* of Observations
by Device and Element
(Thousandths of a Minute)

Device	Elements					
	1	2	3	4	5	6
Auto-graphic	1.0	1.5	1.3	1.5	1.1	1.1
Stop Watch	3.9	5.5	4.6	4.5	3.0	4.7
Wire Recorder	1.4	1.2	1.4	1.7	1.4	0.8
Marsto-chron	5.0	2.3	2.1	2.6	3.5	5.2
Electronic	1.3	1.2	1.5	1.6	1.2	1.0

* These standard deviations were obtained by pooling the variances of the five operators for each combination of device and element. Thus, each standard deviation is based on 5(15-1) = 70 degrees of freedom.

95% confidence interval of σ_x for 70 degrees of freedom

$$\text{Upper Limit} = \sigma_x \sqrt{F_{0.025}(70,\infty)} = \sigma_x \sqrt{1.37} = 1.18\sigma_x$$

$$\text{Lower Limit} = \sigma_x \sqrt{\frac{1}{F_{0.025}(\infty,70)}} = \sigma_x \sqrt{0.71} = 0.85\sigma_x$$

For example: On element one, using the auto-graphic timer, the probability is 0.95 that the interval 0.85 x 1.0 to 1.18 x 1.0 (0.85 to 1.18) contains the true σ_x' of this device for element one.

consistently large minus value for all devices. Apparently an extremely short element (0.0237 min.) introduces these inconsistencies into the data for an element which succeeds it. This indication was also prevalent in a study made by Magar (14).

Based on the significance tests and the analysis of the differences between device means and device standard deviations, the hypothesis that there are real differences between the accuracy and precision of timing devices is accepted. Further indications are that the auto-graphic timer, the wire recorder, and the electronic timer exhibit no significant differences in results.

Qualitative Analysis.--While leveling was not considered an integral part of this study, leveling is an integral part of actual time study work. Therefore, any device used for time study purposes must allow adequate and easy means of recording the leveling factor. As was pointed out in Chapter II, stopwatch time study techniques allow ratings to be recorded; but this becomes extremely difficult when timing short elements of work. The marsto-chron has no means of recording a leveling factor. The auto-graphic timer, the wire recorder, and the electronic timer all offer adequate means of recording leveling factors even for a long series of short elements.

Further analysis was made regarding the relationship of time measurement and the recording of ratings. This was based on quantative reasoning as follows. The coefficient of variation, expressed as a percentage, for any device is given by the equation:

$$CV_d = \frac{\sigma_d}{\bar{x}_d}(100\%)$$

If this is equated to a coefficient of variation for rating ability, the minimum $\bar{x}_d$ can be determined for any given device which will give the equivalent accuracy of rating ability.

A thorough analysis of rating techniques and accuracy is beyond the scope of this study. It is generally accepted by time study men that ratings can be made within ± 10% of the correct value. It seems reasonable, therefore, to expect a coefficient of variation for rating to be approximately 5%. This was assumed and comparison of the devices as shown in Figure 7 was made.

Figure 7 indicates that the minimum elemental time that should be timed with the stopwatch to equal a 5% rating coefficient of variation is 0.088 minute. The marsto-chron could be used to time elements of 0.073 minute while the electronic timer will give accuracy equivalent to that of rating when timing elements of only 0.026 minute duration.

Comparison of Device Coefficients of Variation with Rating Coefficient of Variation

$$CV_{Device} = \frac{\sigma_d}{\bar{x}_d} (100\%)$$

Let $CV_{Rating} = 5\%$

$\sigma_{stopwatch} = 0.00439$; if $CV_{sw} = 5\%$

Then: $\bar{x}_{sw} = \frac{0.439}{5} = 0.088$ min.

$\sigma_{marsto\text{-}chron} = 0.00366$; if $CV_{marsto} = 5\%$

Then: $\bar{x}_{marsto} = \frac{0.366}{5} = 0.073$ min.

$\sigma_{electronic} = 0.00131$; if $CV_{elect} = 5\%$

Then: $\bar{x}_{elect} = \frac{0.131}{5} = 0.026$ min.

Figure 7. Comparison of Device Coefficients of Variation with Rating Coefficient of Variation

CHAPTER V

CONCLUSIONS

Results of the significance tests and analysis of the relative differences between device means and standard deviations lead to the following conclusions:

1. Well qualified time study observers with equivalent training and experience when using the same device will give statistically equivalent results.
2. Of all the devices used in this experiment, the stopwatch produces the least accurate and least precise results; however, there is some indication that well qualified time study observers may have a smaller standard deviation for watch readings than was reported by Lazarus (5), Magar (14), and Leng (37). Excluding the zero deviations, the standard deviations for the stopwatch readings in this experiment ranged from 0.00258 to 0.00676 minute and averaged 0.00439 minute.
3. The marsto-chron gives a somewhat higher degree of accuracy and precision than the stopwatch when timing short elements (0.02 to 0.08 minute) even with well qualified time study observers using the

stopwatch. Standard deviations for the marsto-chron in this experiment ranged from 0.00064 to 0.01135 minute and averaged 0.00366 minute.

4. The auto-graphic timer, the wire recorder, and the electronic timer give statistically equivalent results with respect to both accuracy and precision. The standard deviations for these devices are respectively 0.00124, 0.00135, and 0.00131 minute, with 95% confidence limits of +0.00058 minute and -0.00032 minute.
5. For elements of the range used in this experiment, there is no significant improvement in device accuracy or device precision with an increase in element duration.
6. The stopwatch and the marsto-chron are inadequate for timing and rating elements shorter than 0.09 minute and 0.07 minute respectively, especially when these occur in sequence, while the auto-graphic timer, the wire recorder, and the electronic timer give acceptable accuracy and precision for elements as short as 0.03 minute duration and also have adequate provision for the observer to record his rating.

Limitations.--Consideration should be given certain factors contributing to the results obtained in this experiment.

The effectiveness of the stopwatch as a timing device depends directly upon observational and manipulative ability, hence, on the experience of the observer. However, the other timing devices require merely a tapping of keys; therefore, the degree of experience of the observer was not expected to have a significant effect on the results obtained. Only fully qualified time study observers from one plant were used in this study. This probably allowed a better analysis of devices effect; but it probably reduced the data variability below the level that would be expected from randomly selected observers.

The element structure in this study is synthetic, short, and repeated identically from cycle to cycle without delays or other dynamic factors likely in industrial operations. Also, no ratings were recorded. It is possible that these conditions imposed weaknesses into the study. However, based on an engineering analysis of the devices, it seems reasonable that under actual time study conditions the autographic timer, the wire recorder, and the electronic timer would give results statistically equivalent to those indicated in this study. It also seems reasonable that the stopwatch and the marsto-chron would give statistically less accurate results due the rating problems which have been discussed previously.

CHAPTER VI

RECOMMENDATIONS

Time study techniques and timing devices offer a considerable number of areas for further investigations beyond the scope and time limitations of this experiment. Some of the experimental studies are suggested in the following list:

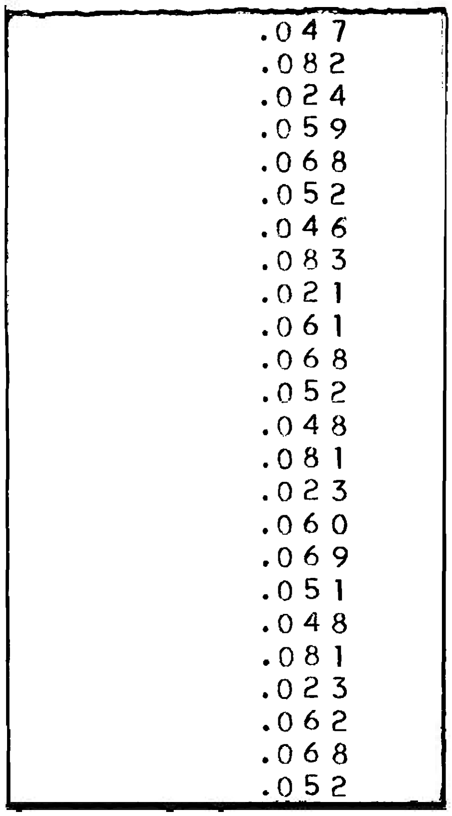
1. An evaluation of other timers such as that of Thuesen (30) could be accomplished through an experiment similar to the present study using either the auto-graphic timer, the electronic timer, or the wire recorder for comparison.
2. An investigation should be made to determine the effect of recording leveling factors on the precision and accuracy of the three devices which showed non-significant differences in this study.
3. Statistical analysis should be made of the three devices which showed non-significant differences in this study when used by both skilled and unskilled time study observers.

4. The method of using three watches as reported by Cyrol (11) seems to have merit for some time study situations. The relative accuracy and precision of this method should be investigated.
5. Experiments should be conducted to verify or refute the possibility that the results of this investigation do not represent those which would occur under actual time study conditions.
6. An investigation should be made of the relative accuracy of predetermined motion-time standards versus time standards established by auto-graphic timer, wire recorder, or electronic timer.
7. There is a need to establish some guide so that the required level of detail and accuracy in work measurement may be more closely related to the requirements of the purpose for which the measurement is made. This would indicate which of the several time study techniques should be used.
8. Investigation should be directed toward finding reasons for the lack of homogeneity of variance within elements which are preceded by very short (0.02 to 0.03 minute) elements.

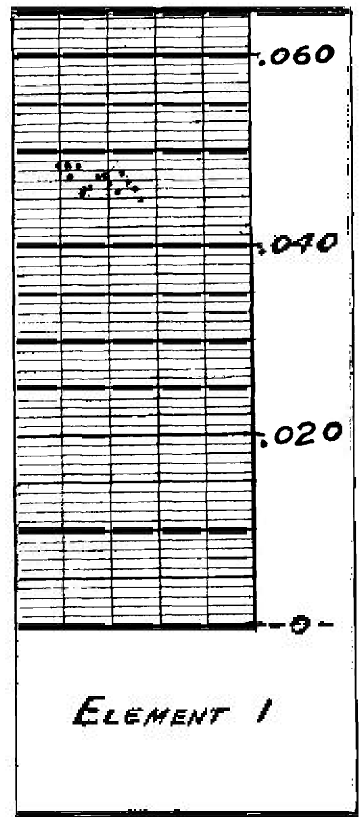
APPENDIX ONE

ORIGINAL DATA
MEANS AND STANDARD DEVIATIONS

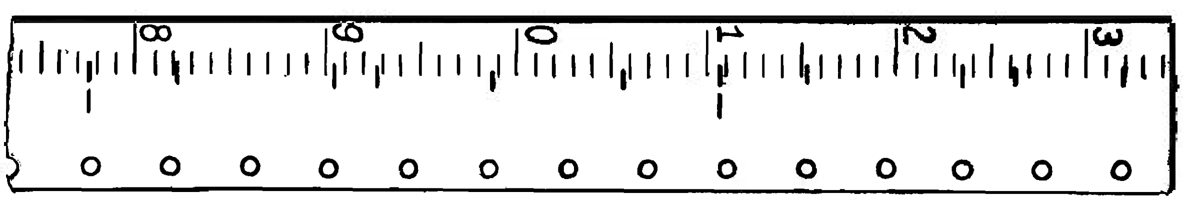
Partial Recordings for Operator D D



Electronic Timer



Auto-graphic Timer



Marsto-chron

Figure 8. Original Recordings

Table 9

Original Data for Electronic Timer
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
	47	82	23	60	71	50
	47	83	24	60	68	52
	46	84	25	58	71	49
	47	83	29	55	68	52
	47	81	24	60	69	52
	45	84	24	59	69	51
	47	83	23	61	68	52
A	46	83	24	60	68	52
	47	84	23	60	68	51
	47	82	24	59	69	51
	48	82	24	59	69	51
	47	83	24	60	68	52
	46	83	26	59	69	53
	43	83	25	59	67	51
	46	84	24	59	70	48
	47	83	23	60	69	53
	46	82	31	53	69	51
	47	82	23	61	69	51
	47	83	25	60	68	52
	45	83	23	61	69	52
	46	82	23	61	69	52
	45	84	22	61	69	51
B	48	82	23	62	68	51
	47	83	22	61	70	50
	48	83	21	64	67	51
	47	83	22	62	68	51
	48	82	25	58	69	52
	48	80	22	60	70	51
	47	82	23	61	69	51
	47	83	22	61	69	52

Table 9. (Continued)

Original Data for Electronic Timer
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
C	47	86	26	56	68	51
	47	81	24	61	70	51
	45	84	22	60	70	51
	48	82	23	60	70	52
	45	84	25	60	74	50
	46	83	24	59	69	51
	47	82	24	60	68	53
	46	83	25	59	69	51
	46	84	23	60	69	53
	45	84	23	60	66	51
	47	83	23	60	69	52
	47	82	23	61	68	52
	47	83	23	60	69	53
	46	82	23	61	69	51
	47	82	23	61	69	53
D	48	82	22	63	68	50
	48	81	25	60	69	51
	47	82	23	62	68	51
	48	82	23	60	68	51
	47	83	24	60	68	52
	48	82	22	61	71	49
	46	83	24	60	69	51
	47	83	25	58	70	51
	47	82	24	59	68	52
	46	83	21	61	68	52
	48	81	23	60	69	51
	48	81	23	62	68	52
	47	82	23	61	68	52
	48	82	24	60	68	51
	54	76	23	61	67	52

Table 9. (Concluded)

Original Data for Electronic Timer
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
	50	79	23	60	69	51
	47	83	27	56	69	52
	47	82	24	59	70	51
	47	83	24	58	70	51
	48	83	24	58	69	52
	48	81	24	60	68	52
E	47	83	24	59	69	52
	46	83	24	59	69	52
	46	82	24	60	73	50
	49	84	24	60	68	52
	46	84	23	60	68	52
	46	83	25	59	68	53
	46	83	23	61	68	52
	46	83	25	58	69	52
	46	83	24	58	69	54

Table 10

Original Data for Marsto-chron
(Thousandths of a minute)

Observer	Elements 1	2	3	4	5	6
A	24	66	35	50	70	48
	45	87	26	54	69	53
	49	77	27	56	69	51
	49	80	26	56	68	51
	47	83	25	59	67	51
	46	83	24	59	68	50
	48	83	23	59	68	51
	48	83	22	60	72	50
	42	83	26	58	69	49
	48	83	23	59	68	52
	47	82	30	54	67	52
	45	82	25	58	70	52
	47	80	23	60	70	50
	46	83	23	64	65	51
	47	82	25	58	68	50
B	47	82	25	58	69	51
	47	83	25	58	67	49
	48	81	26	58	68	52
	46	82	22	62	68	51
	46	84	21	60	68	51
	48	81	23	62	68	50
	46	83	25	62	68	51
	47	83	22	59	68	51
	46	82	24	60	69	52
	47	82	23	60	69	51
	47	82	23	59	69	50
	48	81	23	62	68	51
	47	82	22	61	69	51
	48	80	23	59	69	51
	46	83	23	62	69	51

Table 10. (Continued)

Original Data for Marsto-chron
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
C	20	77	25	59	67	51
	36	83	27	58	73	49
	42	82	26	56	69	52
	47	82	24	62	68	49
	47	83	22	61	68	52
	52	77	25	57	69	53
	36	80	23	63	67	57
	41	82	22	61	68	50
	50	78	23	62	68	54
	41	81	22	60	70	50
	44	82	24	61	70	50
	41	82	23	60	68	51
	44	82	23	61	72	50
	40	83	23	63	65	53
	41	77	27	56	69	52
D	48	80	27	56	69	54
	45	82	23	61	68	50
	46	81	27	58	68	52
	46	83	23	59	70	52
	45	82	24	66	62	52
	48	81	25	59	68	52
	46	80	25	58	69	55
	43	83	22	65	66	49
	48	83	24	59	41	82
	44	85	22	59	67	51
	49	79	27	58	68	50
	47	84	22	63	67	54
	43	82	24	61	74	44
	49	80	21	62	68	49
	47	83	22	63	69	52

Table 10. (Concluded)

Original Data for Marsto-chron
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
	43	83	25	58	69	50
	47	82	23	61	69	51
	46	81	26	58	69	51
	40	87	23	61	69	52
	48	80	25	58	69	52
	27	78	25	59	68	51
	47	82	26	58	68	51
E	34	83	25	58	69	51
	44	81	28	55	69	50
	46	80	25	60	68	52
	48	81	25	58	68	52
	41	82	23	58	69	51
	43	83	25	62	67	50
	46	83	22	62	66	51
	44	83	25	59	67	51

Table 11

Original Data for Wire Recorder
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
A	51	78	25	59	69	53
	43	83	26	58	68	50
	49	80	23	60	66	51
	47	81	26	57	68	51
	47	81	24	61	65	49
	48	80	23	60	69	50
	46	82	24	55	70	49
	46	80	23	60	67	51
	45	82	24	58	66	50
	46	83	24	59	67	50
	45	82	25	58	67	51
	46	82	24	57	67	51
	44	81	24	59	68	50
	47	82	24	65	60	51
	45	83	24	58	67	49
B	48	81	23	62	67	51
	47	81	22	60	68	51
	46	82	22	59	68	51
	45	82	23	59	69	51
	45	83	21	61	68	50
	48	80	22	60	68	51
	45	81	22	60	67	51
	45	83	22	60	68	50
	46	82	25	57	68	50
	45	82	22	59	68	50
	46	81	24	59	66	51
	47	80	24	59	67	50
	47	80	21	61	66	51
	45	81	25	56	69	51
	46	83	23	60	68	50

Table 11. (Continued)

Original Data for Wire Recorder
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
C	46	85	27	54	68	52
	46	83	24	58	68	51
	47	81	22	59	69	51
	45	82	24	58	68	51
	45	82	24	57	68	50
	46	82	22	59	68	50
	46	81	23	65	62	50
	45	81	25	59	67	51
	47	81	22	59	68	50
	46	80	24	58	68	50
	47	81	22	59	67	51
	46	81	23	59	69	50
	47	81	22	59	67	51
	46	82	24	58	68	51
	46	81	22	59	68	50
D	52	79	24	59	69	51
	46	83	24	59	69	50
	46	83	22	59	68	51
	47	81	26	56	68	50
	46	80	23	59	68	49
	47	80	24	60	68	49
	46	82	22	60	67	51
	45	81	24	59	67	50
	47	80	23	57	67	51
	46	80	24	58	68	50
	47	81	24	58	68	50
	46	82	23	59	68	51
	45	81	23	60	67	50
	46	82	22	60	67	50
	47	80	24	58	67	49

Table 11. (Concluded)

Original Data for Wire Recorder
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
	48	83	24	59	68	51
	48	81	24	59	68	51
	46	83	23	58	69	51
	45	82	25	57	68	50
	47	82	23	59	67	50
	47	81	24	59	68	50
	48	81	24	58	68	50
E	48	82	23	60	66	51
	46	82	25	58	67	52
	46	81	29	54	66	51
	46	81	23	58	69	50
	50	78	25	57	68	50
	46	82	24	59	67	51
	47	80	26	57	68	51
	46	82	24	58	67	52

Table 12

Original Data for Stopwatch
(Hundredths of a minute)

Observer	Elements					
	1	2	3	4	5	6
	4	8	2	5	6	5
	4	8	2	5	6	5
	4	8	2	5	6	5
	4	8	2	5	6	5
	4	7	2	5	6	5
	4	8	2	5	6	5
	4	7	2	5	6	5
A	4	7	2	5	6	5
	4	7	2	5	6	5
	4	7	2	5	6	4
	4	7	2	5	6	5
	4	7	2	5	6	4
	4	8	2	4	6	5
	4	8	2	5	6	5
	4	7	2	6	6	5
	4	8	2	6	7	4
	4	6	3	6	7	5
	4	8	2	6	7	4
	4	8	2	5	7	5
	5	8	2	6	7	5
	5	7	2	6	7	5
	5	8	3	5	7	4
B	4	8	3	5	7	5
	4	8	2	5	7	5
	4	9	2	5	6	5
	4	8	2	5	7	5
	5	7	2	5	7	5
	5	8	2	6	7	4
	4	8	2	6	7	4
	4	8	3	5	8	5

Table 12. (Continued)

Original Data for Stopwatch
(Hundredths of a minute)

Observer	Elements					
	1	2	3	4	5	6
C	4	8	2	4	6	4
	4	8	2	5	6	5
	4	8	2	5	6	5
	4	8	2	6	6	5
	4	7	2	5	6	5
	4	7	2	5	6	5
	4	8	2	5	6	5
	4	8	2	5	6	4
	4	8	2	5	6	5
	4	7	2	4	7	4
	4	7	2	5	6	4
	4	7	2	5	6	4
	4	7	2	5	6	4
	4	8	2	6	6	4
	4	8	2	5	6	4
	4	7	2	5	6	4
D	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	5	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	5	6	5
	4	8	2	5	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5
	4	8	2	6	6	5

Table 12. (Concluded)

Original Data for Stopwatch
(Hundredths of a minute)

Observer	Elements 1	2	3	4	5	6
	4	7	2	5	6	5
	4	7	2	5	6	4
	4	7	2	5	6	5
	4	7	2	5	6	4
	4	7	2	5	6	5
	4	8	2	5	6	4
	4	8	2	4	6	5
E	4	8	2	5	7	5
	4	7	2	5	6	5
	4	7	2	5	6	5
	4	7	2	5	6	5
	4	8	2	5	6	5
	4	7	2	6	6	5
	5	7	2	5	6	5
	4	7	2	5	6	4

Table 13

Original Data for Auto-graphic Timer
(Thousandths of a minute)

Observer	Elements 1	2	3	4	5	6
A	48	81	23	61	67	50
	48	81	24	60	67	48
	50	81	26	57	68	50
	47	81	23	60	69	51
	47	82	22	59	70	49
	47	80	24	59	68	51
	48	80	23	59	70	49
	48	79	24	60	68	49
	47	82	25	58	68	50
	48	80	25	58	68	50
	46	83	25	57	69	50
	48	81	24	58	69	51
	46	81	23	59	69	50
	47	82	22	60	68	50
	48	81	24	57	69	52
B	47	82	23	60	68	50
	46	83	23	60	68	50
	47	82	24	59	68	50
	47	81	22	60	69	49
	48	81	22	60	68	50
	47	82	23	61	67	50
	46	82	21	61	68	50
	45	84	22	61	67	50
	46	82	22	63	67	51
	45	82	24	59	68	50
	47	81	22	61	69	50
	46	83	25	57	69	49
	48	81	22	61	69	50
	46	83	24	58	68	51
	46	82	22	60	69	50

Table 13. (Continued)

Original Data for Auto-graphic Timer
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
C	55	75	24	58	68	49
	46	84	25	59	66	51
	46	82	24	61	66	50
	46	82	23	61	68	48
	46	82	23	61	67	50
	46	82	23	59	70	48
	47	82	21	61	72	44
	47	83	24	58	68	49
	48	82	23	60	68	49
	48	81	23	59	68	50
	45	83	23	60	68	50
	47	83	22	59	68	51
	46	82	22	62	66	50
	46	83	22	62	67	49
	46	83	25	58	70	47
D	49	81	25	56	67	49
	49	80	27	56	68	50
	47	81	25	58	68	50
	48	80	23	59	68	50
	46	83	27	56	66	51
	46	82	25	58	68	51
	46	81	24	58	68	50
	47	81	24	60	68	50
	48	82	27	55	68	50
	47	82	23	59	67	49
	46	83	25	59	67	51
	48	80	24	59	68	51
	47	82	23	59	68	50
	46	83	23	59	67	51
	45	82	23	61	62	52

Table 13. (Concluded)

Original Data for Auto-graphic Timer
(Thousandths of a minute)

Observer	Elements					
	1	2	3	4	5	6
	47	83	28	55	68	50
	47	81	25	57	69	50
	47	81	27	58	66	50
	48	81	26	56	69	50
	47	82	24	58	68	51
	46	81	25	59	66	51
	46	82	25	59	67	51
E	46	82	23	60	67	51
	48	80	25	57	68	50
	48	82	23	58	69	51
	46	81	23	60	68	50
	46	81	27	57	67	52
	48	80	26	57	68	52
	46	82	23	60	68	51
	47	82	25	57	69	52

Table 14

Means of Observations
(Thousandths of a minute)

D_j	M_i	Elements 1	2	3	4	5	6
I	A	47.53	81.00	23.80	58.80	68.47	50.00
	B	46.46	82.07	22.73	60.06	68.13	50.00
	C	47.00	81.93	23.13	59.86	68.00	49.00
	D	47.00	81.53	24.53	58.13	67.20	50.33
	E	46.86	81.40	25.00	57.86	67.80	50.80
II	A	40.00	74.30	20.00	50.00	60.00	48.00
	B	43.30	78.00	22.60	54.30	70.00	46.60
	C	40.00	75.30	20.00	50.00	60.60	44.00
	D	40.00	80.00	20.00	58.00	60.00	50.00
	E	40.60	72.70	20.00	50.00	60.60	47.30
III	A	46.33	81.33	24.20	58.93	66.93	50.40
	B	46.06	81.47	22.73	59.46	67.67	50.60
	C	46.06	81.60	23.33	58.66	67.53	50.60
	D	46.60	81.00	23.46	58.73	67.73	50.13
	E	46.93	81.40	24.40	58.00	67.60	50.73
IV	A	45.20	81.13	25.53	57.60	68.53	50.73
	B	46.93	82.07	23.20	60.13	68.40	50.86
	C	41.46	80.73	23.93	60.00	68.73	51.53
	D	46.26	81.87	23.86	60.46	66.26	53.20
	E	42.93	81.93	24.73	59.00	68.27	51.06
V	A	46.40	82.93	24.40	59.20	68.80	51.13
	B	46.86	82.47	23.33	60.40	68.80	51.40
	C	46.40	83.00	23.60	59.86	69.13	51.66
	D	47.80	81.67	23.33	60.53	68.47	51.20
	E	47.00	82.60	24.13	59.00	69.07	51.86

Table 15

Standard Deviations of Original Observations
(Ten thousandths of a minute)

D_j	M_i	Elements					
		1	2	3	4	5	6
I	A	9.90	10.00	10.35	12.59	9.15	10.00
	B	9.15	8.83	10.65	14.38	7.43	5.34
	C	12.06	26.57	11.26	14.08	16.47	17.74
	D	11.96	10.72	15.04	16.86	7.27	8.17
	E	8.10	8.28	16.03	15.17	10.14	7.74
II	A	0	51.66	0	37.79	0	41.42
	B	48.78	67.61	45.78	51.66	37.79	48.79
	C	0	51.64	0	53.45	25.82	50.71
	D	0	0	0	41.42	0	0
	E	25.82	45.77	0	37.79	25.82	45.77
III	A	19.87	13.73	9.41	22.53	23.13	10.54
	B	10.14	10.62	13.95	15.05	8.99	5.07
	C	7.04	11.84	14.48	18.48	16.43	6.32
	D	16.39	11.96	10.61	11.77	7.04	7.43
	E	12.79	12.42	19.56	14.18	9.10	7.03
IV	A	61.32	35.22	33.12	32.67	16.46	12.79
	B	7.99	10.26	13.21	15.06	6.39	7.43
	C	71.79	23.13	17.09	23.29	15.31	21.32
	D	15.99	16.82	19.95	28.51	74.01	113.49
	E	57.91	20.16	14.86	18.89	9.61	7.04
V	A	11.84	8.84	15.02	13.72	11.45	13.03
	B	9.90	9.16	23.81	24.14	7.75	7.37
	C	9.10	12.54	10.54	12.46	16.82	9.76
	D	18.59	17.18	11.14	12.47	9.90	8.62
	E	12.53	12.42	9.90	12.53	13.38	9.16

APPENDIX TWO

STATISTICAL ANALYSES

Table 16

Mean Squares for Element 1

Mean Squares of $\bar{\bar{x}}$'s

Source of Variance	df	Sum of Squares ($\times 10^{-4}$)	Mean Square ($\times 10^{-4}$)	F	Sig. Level*	df_p	Pooled Error Mean Square	F_p
Devices	4	1.361	0.340	28.4	<0.001	4	0.340	22.6
Observers	4	0.088	0.022	1.79	>0.1			
Order	4	0.090	0.023	1.83	>0.1			<0.001
Residual	12	0.147	0.012			20	0.015	
Total	24	1.643						

* Sig. Level of 0.001 means that the F ratio exceeds the tabular value of F having an area of 0.001 to the right.

Mean Squares of σ's

Source of Variance	df	Sum of Squares *	Mean Square *	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	3	3.567	1.189	3.94	<0.05	3	1.189	4.32
Observers	4	0.767	0.192					<0.05
Residual	12	3.628	0.302			16	0.275	
Total	19	7.962						

* Sum of Squares were calculated for $\ln(\sigma \times 10^6)$.

Table 17

Mean Squares for Element 2

Mean Squares of $\overline{x}$'s

Source of Variance	df	Sum of Squares ($x10^{-4}$)	Mean Square ($x10^{-4}$)	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	4	1.309	0.327	16.4	<0.001	4	0.327	18.2
Observers	4	0.066	0.016	-				<0.001
Order	4	0.069	0.017	-				
Residual	12	0.234	0.020			20	0.018	
Total	24	1.678						

Mean Squares of σ's

Source of Variance	df	Sum of Squares *	Mean Square *	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	3	0.847	0.282	2.91	>0.05	3	0.847	2.49
Observers	4	0.640	0.160	1.65	>0.1			>0.05
Residual	12	1.167	0.097			16	0.113	
Total	19	2.654						

* Sum of Squares were calculated for $\ln(\sigma x10^6)$.

Table 18

Mean Squares for Element 3

Mean Squares of $\bar{x}$'s

Source of Variance	df	Sum of Squares ($x10^{-4}$)	Mean Square ($x10^{-4}$)	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	4	0.456	0.114	8.1	<0.005	4	0.114	11.4
Observers	4	0.031	0.008	-				<0.001
Order	4	0.009	0.002	-				
Residual	12	0.165	0.014			20	0.010	
Total	24	0.661						

Mean Squares of σ's

Source of Variance	df	Sum of Squares *	Mean Square *	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	3	0.442	0.147	1.35	>0.1	3	0.147	1.73
Observers	4	0.045	0.011	-				>0.1
Residual	12	1.309	0.109			16	0.085	
Total	19	1.796						

* Sum of Squares were calculated for $\ln(\sigma x10^{6})$.

Table 19

Mean Squares for Element 4

Mean Squares of $\bar{x}$'s

Source of Variance	df	Sum of Squares ($x10^{-4}$)	Mean Square ($x10^{-4}$)	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	4	1.839	0.460	16.4	<0.001	4	0.460	13.9
Observers	4	0.248	0.062	2.2	>0.1			<0.001
Order	4	0.077	0.019	-				
Residual	12	0.336	0.028			20	0.033	
Total	24	2.500						

Mean Squares of σ's

Source of Variance	df	Sum of Squares *	Mean Square *	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	3	0.649	0.216	3.32	>0.05	3	0.216	3.93
Observers	4	0.099	0.025					<0.05
Residual	12	0.778	0.065			16	0.055	
Total	19	1.526						

* Sum of Squares were calculated for $\ln(\sigma x10^6)$.

Table 20

Mean Squares for Element 5

Mean Squares of $\bar{x}$'s

Source of Variance	df	Sum of Squares ($x10^{-4}$)	Mean Square ($x10^{-4}$)	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	4	1.412	0.353	8.6	<0.005	4	0.353	8.6
Observers	4	0.200	0.050	1.2	>0.1			
Order	4	0.119	0.029	-				<0.005
Residual	12	0.494	0.041			20	0.041	
Total	24	2.225						

Mean Squares of σ's

Source of Variance	df	Sum of Squares*	Mean Square	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	3	0.662	0.221	-				
Observers	4	1.251	0.313	1.13	>0.1	4	0.313	1.18
Residual	12	3.321	0.277			15	0.266	>0.1
Total	19	5.234						

*Sum of Squares were calculated for $\ln(\sigma x10^6)$.

Table 21

Mean Squares for Element 6

Mean Squares of $\bar{\bar{x}}$'s

Source of Variance	df	Sum of Squares ($x10^{-4}$)	Mean Square ($x10^{-4}$)	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	4	0.621	0.155	14.1	<0.001	4	0.155	11.9
Observers	4	0.069	0.017	1.5	>0.1			<0.001
Order	4	0.051	0.013	1.2	>0.1			
Residual	12	0.136	0.011			20	0.013	
Total	24	0.877						

Mean Squares of σ's

Source of Variance	df	Sum of Squares *	Mean Square *	F	Sig. Level	df_p	Pooled Error Mean Square	F_p
Devices	3	1.963	0.654	2.06	>0.1	3	0.654	1.83
Observers	4	1.919	0.479	1.51	>0.1			>0.1
Residual	12	3.799	0.317			16	0.357	
Total	19	7.681						

* Sum of Squares were calculated for $\ln(\sigma x10^6)$.

Table 22

Analysis of Variance
Two-way Table
(Element 2)

Transformation = $\bar{x}(10^2)$

M_i / D_j	A	B	C	D	E	$\sum_A^E$
I	8.10	8.21	8.19	8.15	8.14	40.79
II	7.46	7.80	7.53	8.00	7.27	38.06
III	8.13	8.15	8.16	8.10	8.14	40.68
IV	8.11	8.15	8.16	8.10	8.14	40.77
V	8.29	8.24	8.30	8.17	8.26	41.26
$\sum_I^V$	40.09	40.61	40.25	40.61	40.00	201.56
$\sum_a^e$	40.51	40.32	40.68	40.06	39.99	$\sum_A^E \sum_I^V$

Transformation = $\ln(\sigma \times 10^6)$

M_i / D_j	A	B	C	D	E	$\sum_A^E$
I	6.97	6.86	7.89	7.03	6.80	35.55
III	7.26	7.02	7.12	7.13	7.17	35.70
IV	8.16	6.99	7.76	7.45	7.62	37.98
V	6.86	6.89	7.18	7.47	7.17	35.57
$\sum_I^V$	29.25	27.76	29.95	29.08	28.76	144.80

Table 23

Analysis of Variance
Two-way Table
(Element 3)

Transformation = $\overline{x}(10^2)$

M_i / D_j	A	B	C	D	E	$\sum_A^E$
I	2.38	2.27	2.31	2.45	2.50	11.91
II	2.00	2.26	2.00	2.00	2.00	10.26
III	2.42	2.27	2.33	2.35	2.44	11.81
IV	2.55	2.32	2.39	2.39	2.47	12.12
V	2.44	2.33	2.36	2.33	2.41	11.87
$\sum_I^V$	11.79	11.45	11.39	11.52	11.82	57.97
$\sum_a^e$	11.77	11.53	11.63	11.55	11.49	$\sum_A^E \sum_I^V$

Transformation = $\ln(\sigma x 10^6)$

M_i / D_j	A	B	C	D	E	$\sum_A^E$
I	7.00	7.02	7.08	7.35	7.41	35.86
III	6.92	7.28	7.31	7.02	7.60	36.13
IV	8.10	7.23	7.47	7.61	7.34	37.75
V	7.35	7.78	7.02	7.07	6.96	36.18
$\sum_I^V$	29.37	29.31	28.88	29.05	29.31	145.92

Table 24

Analysis of Variance
Two-way Table
(Element 4)

Transformation = $\overline{x}(10^2)$

D_j \ M_i	A	B	C	D	E	$\sum_A^E$
I	5.88	6.01	5.99	5.81	5.79	29.48
II	5.00	5.46	5.00	5.80	5.00	26.26
III	5.89	5.95	5.87	5.87	5.80	29.38
IV	5.76	6.01	6.00	6.05	5.90	29.72
V	5.92	6.04	5.99	6.05	5.90	29.90
$\sum_I^V$	28.45	29.47	28.85	29.58	28.39	144.74
$\sum_a^e$	29.16	28.70	29.39	28.70	28.79	$\sum_A^E \sum_I^V$

Transformation = $\ln(\sigma x 10^6)$

D_j \ M_i	A	B	C	D	E	$\sum_A^E$
I	7.18	7.31	7.29	7.45	7.36	36.59
III	7.73	7.35	7.54	7.12	7.29	37.03
IV	8.09	7.40	7.76	7.96	7.56	38.77
V	7.26	7.80	7.17	7.17	7.18	36.58
$\sum_I^V$	30.26	29.86	29.76	29.70	29.39	148.97

Table 25

Analysis of Variance
Two-way Table
(Element 5)

Transformation = $\bar{\bar{x}}(10^2)$

$D_j \backslash M_i$	A	B	C	D	E	$\sum_A^E$
I	6.85	6.81	6.80	6.72	6.78	33.96
II	6.00	7.00	6.06	6.00	6.06	31.12
III	6.69	6.77	6.75	6.77	6.76	33.74
IV	6.85	6.84	6.87	6.63	6.83	34.02
V	6.88	6.88	6.91	6.85	6.91	34.43
$\sum_I^V$	33.27	34.30	33.39	32.97	33.34	167.27
$\sum_a^e$	34.14	33.35	33.29	33.22	33.27	$\sum_A^E \sum_I^V$

Transformation = $\ln(\sigma \times 10^6)$

$D_j \backslash M_i$	A	B	C	D	E	$\sum_A^E$
I	6.89	6.71	7.41	6.69	6.98	34.68
III	7.76	6.88	7.43	6.66	6.89	35.62
IV	7.43	6.57	7.36	8.89	6.94	37.19
V	7.10	6.74	7.45	6.96	7.23	35.48
$\sum_I^V$	29.18	26.90	29.65	29.20	28.04	142.97

Table 26

Analysis of Variance
Two-way Table
(Element 6)

Transformation = $\bar{x}(10^2)$

$D_j \backslash M_i$	A	B	C	D	E	$\sum_A^E$
I	5.00	5.00	4.90	5.03	5.08	25.01
II	4.80	4.66	4.40	5.00	4.73	23.59
III	5.04	5.06	5.06	5.01	5.07	25.24
IV	5.07	5.09	5.15	5.32	5.11	25.74
V	5.11	5.14	5.17	5.12	5.19	25.73
$\sum_I^V$	25.02	24.95	24.68	25.48	25.18	125.31
$\sum_a^e$	25.23	24.63	25.18	25.06	25.21	$\sum_A^E \sum_I^V$

Transformation = $\ln(\sigma x 10^6)$

$D_j \backslash M_i$	A	B	C	D	E	$\sum_A^E$
I	6.97	6.42	7.50	6.79	6.74	34.42
III	7.02	6.38	6.57	6.71	6.66	33.34
IV	7.20	6.38	6.57	6.71	6.66	33.34
V	7.21	6.70	6.95	6.84	6.89	34.59
$\sum_I^V$	28.40	26.21	28.70	29.65	26.95	139.91

APPENDIX THREE

OBSERVER DATA

INSTRUCTIONS TO OBSERVERS

Personal Data Sheet

of Thesis Participating Observers

Full Name Edgar M. Rutledge Age 36

Schooling High School

Type of experience prior to
Time Study Repair of Aircraft

Length of time study training 3 months

Length of time study experience 3½ years

Wear glasses? No

Left handed Right handed xx

Learning Ability test score (possible 90) 58

Figure 9. Personal Data Sheet -- Observer A

Personal Data Sheet

of Thesis Participating Observers

Full Name Thomas W. Dempsey Age 37

Schooling High School

Type of experience prior
to Time Study Aircraft Mechanic

Length of time study training 3 months

Length of time study experience 3 years

Wear glasses? No

Left handed ______ Right handed xx

Learning Ability test score (possible 90) 72

Figure 10. Personal Data Sheet -- Observer B

Personal Data Sheet

of Thesis Participating Observers

Full Name Charles E. George Age 50

Schooling High School

Type of experience prior
to Time Study Machinist

Length of time study training 3 months

Length of time study experience 3 years

Wear glasses? Yes

Left handed ______ Right handed xx

Learning Ability test score (possible 90) 72

Figure 11. Personal Data Sheet -- Observer C

Personal Data Sheet

of Thesis Participating Observers

Full Name LeRoy C. Whitaker Age 38

Schooling High School

Type of experience prior to Time Study Aircraft Mechanic

Length of time study training 3 months

Length of time study experience 4 years

Wear glasses? No

Left handed ________ Right handed xx

Learning Ability test score (possible 90) 64

Figure 12. Personal Data Sheet -- Observer D

Personal Data Sheet

of Thesis Participating Observers

Full Name Ralph F. Cox Age 39

Schooling High School

Type of experience prior
to Time Study Repair of Electronics Equipment

Length of time study training 3 months

Length of time study experience 3 years

Wear glasses? Yes

Left handed ______ Right handed xx

Learning Ability test score (possible 90) 69

Figure 13. Personal Data Sheet -- Observer E

INSTRUCTIONS TO OBSERVERS

1. As you know, time study is a method of measuring the work content of human tasks. This method requires a measurement of the time consumed in performing the work. It implies careful measurement of all the work elements of an operation by means of some precision instrument developed for that purpose.

2. Also, I'm sure you are aware that the variability of individual observations in your time studies contains two elements, variability of the process being timed (timed variance), and variability of your measurement (timing variance). Of course, the worker (or process) controls the timed variance, but the timing variance is due to the characteristics of you, the observer, and the device you are using.

3. Now, for a moment, let's assume that we have the "best" method for an operation and that we have a fully qualified normal operator performing that operation. Let's further assume that the ease and accuracy of leveling would be equal regardless of which timing device is being used. It follows, then, that if the variability of observation can be reduced, the number of observations also can be reduced.

4. Therefore, the purpose of this study is to determine whether time study observers, when using different types of timing devices, exhibit a significant difference in the precision and accuracy with which they read and record time intervals between the terminal points of work elements. In order to determine this, we must follow a definite procedure. Each of you has been assigned a letter (A, B, C, etc.), and each timing device has been assigned a number (I, II, III, etc.). This was done by random selection. Each of you also has been assigned a definite order in which to use the devices. I will give those to you now.

Figure 14. Instructions to Observers

5. In the order which you have just been assigned, each of you will time fifteen cycles of light flashes generated by this machine. There are six red flashes each cycle and one white flash to designate the end of a cycle. By using this machine to generate element end points rather than using an actual operation, the timed variance is reduced to the point that it is not significantly different from zero. The first fifteen cycles of timing on each device will be practice. This will acquaint you with the characteristics of each device, and also you will become familiar with elemental breakdown of the cycle. Since each of you has used snap-back timing in your regular work, we will use that method for the stopwatch here. After the fifteen cycles of practice, you will then time fifteen cycles, again in the proper order, to record the data which will be statistically analyzed.

6. Are there any questions at this point? ...I will now demonstrate the proper use of each of the devices.

Figure 14. Instructions to Observers (Continued)

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